The Need for A Robust Planet Finding Community:

Research Support and Community Archives[1]

Submitted by Charles Beichman[2], David Ciardi[2], Doug Lin[3], Wes Traub[4]

Summary

A long term program to find and characterize planets beyond our solar system and to search for life requires a stable base of funding for many activities: ensuring steady observational and theoretical progress in our understanding of exo-planets; nurturing the innovative instrument builders who will develop the exacting measurement techniques needed for planet finding; providing attractive career paths for young scientists; obtaining the requisite precursor measurements of nearby stars; and curating and cross-correlating important datasets. Recent budget cuts have disrupted the research "ecosystem" of the planet finding community. Redressing these cuts would cost approximately \$10M/yr above the present level of Research and Analysis (R&A) support and should be an important recommendation of the ExoPlanet Task Force. This White Paper addresses only the R&A program and infrastructure needs of the planet-finding community. For a vision of the overall program, including recommendations for space missions of various sizes, the Task Force should consult other White Papers, including one giving an overall description of the Navigator Program (Traub et al).

Research and Analysis Support for Planet Finding

The quest to find planetary systems and to search for life will be a long-term project. In endorsing planet-finding as an important new field of research, the 2000 NAS/NRC Decadal Committee (*Astronomy and Astrophysics in the New Millennium*, *p 29*) noted that "[To] Search for Life outside of earth and, if it is found, determine its nature and its distribution in the galaxy... is so challenging and of such importance that it could occupy astronomers for the foreseeable future." A national program of the scope being considered by the ExoPlanet Task Force demands a robust program covering many aspects of research, as highlighted in the recent report of NASA's *Strategic Roadmap Working Group #4* (2006):

> "The integration of many disciplines is required to explore Earth-like worlds and habitable environments; this points to a need for cross-trained teams of scientists, technologists, and engineers. The planet-finding missions utilize a variety of space-based and ground-based telescopes, as well as a rich program of research and analysis, laboratory astrophysics, and theoretical investigations supported by Research and Analysis (R&A). This is a diverse environment in which to train the STEM [Scientific, Technological, Engineering and Mathematical] workforce who will actually conduct

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[2] Michelson Science Center, California Institute of Technology
[3] University of California, Santa Cruz
[4] Jet Propulsion Laboratory, California Institute of Technology.

> missions in the future. Programs of scholarships, fellowships, and training for undergraduate, graduate, and post-doctoral scientists and engineers should be supported via academic and research institutions, NASA centers, and in industry."

In the context of the charge to the ExoPlanet Task Force, it is important to emphasize that a broad program of Research and Analysis (R&A) is vital to success of the overall enterprise:

- We must train and nurture young scientists and provide opportunities for talented mid-career scientists to enter and contribute to the field of exo-planet astrophysics.
- Exo-planet research of modest scope can be carried out while the community awaits an improved budget environment to initiate larger-scale projects. Significant research opportunities can be made available through relatively modest programs, e.g., transit surveys taken with relatively small telescopes (some as small as 10 cm); radial velocity search programs with 2-10 m telescopes; new observations and archival data from existing space missions such as Spitzer and HST; and broad community access to data from PI-class space missions such as Kepler and CoRoT. Some support is available in these areas (HST and Spitzer), some areas have been cut (TPF Foundation Science), and some remain to be arranged (support for community research utilizing CoRoT and Kepler data).
- Theoretical work is essential to interpret observations that have been intensely surprising since the initial discoveries of pulsar planets and hot Jupiters. Theory programs must incorporate new results to enrich our understanding of the formation and evolution of planetary systems and to make predictions that will guide new observational efforts. For example, theories of planet formation and solar system dynamics are essential to extrapolate from today's improving, but still limited knowledge of the frequency of terrestrial planets (η_{Earth}) to help set the size and scope of direct detection missions. Astrobiology theory programs are needed to improve our understanding of the atmospheres of terrestrial planets under variety of astrophysical conditions and to identify potential biomarkers spanning a significant fraction of a planet's lifetime.
- Data gathering activities will provide increasing volumes of data, particularly transit surveys covering hundreds to thousands of square degrees and yielding light curves for hundreds of thousands of stars with temporal baselines of months to years. Data archives must integrate disparate datasets to allow efficient access by the broad community.
- Planet finding is inherently demanding of the best new ideas in technology, ranging from advances in radial velocity measuring capabilities to innovative concepts for direct detection of infrared or visible light from planets. The technologies for future missions demand significant development at the nation's universities, NASA Centers, and industry.

Current R&A Status

While funding remains in the system, particularly through the HST and Spitzer observatories, the research support dedicated to general exo-planet research has been cut significantly between FY04 and FY07, with a 44% cut in the overall level of funding of relevant R&A programs (Table 1). The over-subscription rates for the remaining opportunities have risen drastically as suggested by the number of Michelson Fellowships awards relative to the number of applications. Technology funding in academia and industry for planet detection techniques has taken drastically larger cuts. The funding profile varies from program to program with some restorations in 2007 relative to 2006, but the overall downward trend and uncertainty in NASA's funding make it difficult to attract and retain the best people.

Table 1. Competitive Research Programs for Planet Finding				
Year	***FY04 Total***	***FY05 Total***	***FY06 Total***	***FY07 Total***
TPF Foundation Science	$1.8M	$1.7M	$0.0M	$0.0M
Origins of Solar System (exo-planet portion)	$4.2M	$3.9M	$4.1M	$3.5M
TPF Technology Awards (University)	$3.1M	$2.5M	$1.2M	$0.7M
Michelson Fellowships Awards/Applications/Funding	6/27 $2.1M	6/32 $2.0M	0/0 $1.2M	7/52 $1.5M
Keck Data Awards	$0.45M	$0.45M	$0.15M	$0.75M
Competed University Research (Total of above 5 rows)	*$11.6M*	*$10.6M*	*$6.7M*	*$6.5M*
TPF Technology Awards (Industry)	$9.7M	$9.1M	$1.1M	$0.6M

- The combination of the two key NASA R&A programs for planet finding, TPF Foundation Science and the Origins of Solar Systems, was cut by 42% between FY04 and FY07.
- The Astrobiology program has been cut by approximately 50% in FY06 and FY07, including investigations to calculate the appearance and detectability of Earth-like planets under different assumptions about the host stars and geological evolution. The astrobiology instrument program (ASTID) which supported about $1M in planet detection technology has been suspended.
- Other NASA funding sources to support students and postdocs, including the Long Term Space Astrophysics (LTSA) program, have been reduced or eliminated.
- The Michelson Fellowship program has supported the research and training of more than 45 graduate student and postdoctoral fellows in all areas of planet finding (http://msc.caltech.edu/michelson/postdocRecipients.html) over the last 7 years. Because of a 50% budget cut in 2006 no selections were made in that year. Fortunately, funding for this program was restored partially in 2007. Similarly, Keck Observer funding was eliminated in 2006, except for travel support, but was restored in 2007.
- Although not explicitly an R&A activity, direct mission support for research into enabling technologies for various planet detection projects has been drastically cut at universities and in industry (Table 1). This funding successfully helped to develop and validate new instrument concepts that promise to decrease the cost and risk of planet detection missions while greatly increasing their scientific yield.

Recommendations For a More Robust Program

At a minimum, we advocate a restored R&A program that supports at least 2-3 highly competitive teams in each of the basic indirect planet detection methods ---radial velocity, transits, microlensing, and astrometry. Direct detection techniques – interferometric, coronagraphic, and direct photometric/spectroscopic measurements (e.g. transits or light curves) would be similarly supported. There should also be 2-3 competitively selected teams engaged in a variety of theoretical studies, e.g. solar system dynamics, planet formation, planetary atmospheres and interiors, dust disks, and biomarkers. This level of activity demands 45-50 grants in total at roughly $100k/year for a total of $5M/yr, roughly $1.5M more than is currently available.

A more vigorous approach would provide an additional $1-2M/yr for technology development and for advanced ground-based instruments, e.g. a high resolution near-IR spectrograph for RV planet searches toward M stars and young stars, a wide-field, high resolution, multi-object spectrograph, or an advanced coronagraph implementing one or more of the innovative designs now under consideration for future space missions. The instrument development portion could be administered through a program similar to the NSF/TSIP program benefiting the entire community.

Finally, for an additional ~$5M/yr, NASA and/or NSF could support 1 or 2 dedicated facilities related to planet finding, e.g balloon-borne or Antarctica-based telescopes, global transit or microlensing networks, or a national interferometer facility.

The funding level available in 2004 coupled with the exciting advances in the field brought about a dramatic influx of researchers that led directly to the still more exciting discoveries we are witnessing today. The attractiveness of this field is testified to by large numbers of students expressing interest at universities around the country and the associated hiring of exo-planet researchers at major research universities, e.g. Harvard, Princeton, UC Santa Cruz, MIT, Univ. of Washington and UC Berkeley. However, the declining and sporadic budgets of the past two years threaten to derail this compelling momentum. The Task Force should recommend that NASA and NSF provide an increased and more stable level of support for R&A grants for a broad range of observing opportunities, for theoretical investigations including relevant astrobiology efforts, graduate student and postdoctoral Fellowships, precursor observations, data archiving, and technology development.

Totaling up the recommendations listed above suggests that $10M/yr above the level of the current R&A program would invigorate a vibrant research community and produce exciting results across a broad front. The effort described herein should be funded in a coordinated fashion by NASA and the NSF. Some of these activities should be continued through the Navigator Program, e.g. Michelson Fellowships through the Michelson Science Center and TPF technology through the TPF project. Within NASA, however, most of the proposed new activities should have a new, stand-alone element in the ROSES program and not be mixed in with other programs, e.g. the Origins of Solar Systems which covers other areas in planetary astrophysics.

Infrastructure Support for the Planet Finding

The diversity and volume of data concerning exo-planets and their host stars is increasing daily with dozens of new planets being discovered annually. These numbers will increase dramatically as transit surveys come into full operation. Individual planet discovery programs will require significant ground-based and space-based data for confirmation of the planetary status of detected companions, the characterization of the host stars, and the creation of target input catalogs. In this context, information on stars which are not (yet) known to host planets may reveal important clues to the planet formation process, so the null results on the much larger number of stars that have been measured with one or more techniques must also be retained and made available.

Our understanding of the physical properties of extra-solar planets and the environments in which they form and evolve will benefit greatly by combining data sets from different sources and across a wide range of the electromagnetic spectrum. In its need for multi-wavelength, multi-dimensional datasets, learning about formation and evolution of planetary systems resembles cosmological investigations into the value of the Hubble constant or the nature of dark energy and dark matter. In both cases, the combination of various observational techniques yields information and reductions of uncertainties impossible to obtain from individual techniques taken separately. For example, in the case of exo-planets, the combination of radius information from transits with mass measurements from radial velocities yields planetary density, a key indicator of a planet's physical structure and evolutionary history. The combination of a transit radius with precision optical photometry yields an albedo (or an upper limit), or when coupled with infrared photometry and spectroscopy yields an effective temperature and information on atmospheric composition and dynamics.

Thus, the maturing field of extra-solar planet research must:

- Have widely available access to data from a large variety of facilities (ground and space based);
- Have widely available access to planet finding data on both stars known to host exo-planets and stars surveyed with null results;
- Combine and analyze multi-wavelength data sets from different sources;
- Understand the specifics of the individual data sets;
- Use common standards (FITS, VO, etc) across individual sub fields;
- Incorporate laboratory data and models based on theory for full insight.

While large missions like HST, Spitzer, Kepler or CoRoT will archive their mission datasets, there are currently only a few efforts to curate and distribute the spectroscopic, imaging, photometric and radial velocity monitoring which are being obtained through existing planet finding programs, or through the preparatory or follow-up programs for SIM, Kepler, CoRoT and TPF/Darwin. There is little or no effort to cross-link and collate these datasets in a coherent manner. NASA, through the Michelson Science Center (MSC; http://msc.caltech.edu), is developing two archives relevant to planet finding:

- The Keck Observatory Archive (KOA; http://msc.caltech.edu/archives/koa/) provides public access to all Keck/HIRES data which forms the foundation of much of what is presently known about exoplanets.
- The NASA Stellar and Exo-Planet Database (NStED; http://msc.caltech.edu/archives/nsted/) is focused on collecting, curating, and serving information known about potential planet bearing stars. Initially, the archive is focused on stars within the Solar Neighborhood and contains a variety of published measurements of positions, kinematics, photometry, multiplicity, activity, and other stellar properties. Following the model of the highly successful NASA Extragalactic Database (NED), the NStED team searches the scientific literature for appropriate information. NStED will provide access to images and spectra beyond simple catalog data, e.g. serving the observed spectral templates for each of the N2K target stars being observed with Keck/HIRES. NStED is being expanded to include a Transit and Stellar Variability (TranSVar) archive to provide community access to light curves for hundreds of thousands of stars to complement space-based transit datasets from Kepler and CoRoT.

These efforts are being coordinated with Europe through the Planet Finding Data Archive Working Group which reports to both ESA and NASA on opportunities for setting data standards and identifying datasets appropriate for archiving on behalf of the community. ESA is supporting a project similar to NstED with a European effort to collect data on the target candidates for the TPF/Darwin missions. The Darwin Archive Madrid (DAMA) utilizes the online resources of Vizier to serve data and provide estimates of stellar properties, and will archive observational data specifically obtained for Darwin/TPF.

Summary

This white paper has focused on how a reinvigorated R&A program would support an overall program that will eventually accomplish the dramatic goals of finding other earths and searching for life beyond the solar system. Relatively modest resources compared with the overall cost of a planet finding mission should be made available for small and moderate scale activities. An R&A program encompassing observational and theoretical investigations, training of students and postdocs, technology development, and collation and curation of important data archives would make major scientific advances while providing the solid foundation of trained personnel and scientific understanding needed for the major ground- and space- missions initiatives under consideration by the Exoplanet Task Force.